

## Research Article

# An Investigation on Strength Development of Cement with Cenosphere and Silica Fume as Pozzolanic Replacement

K. Senthamarai Kannan,<sup>1</sup> L. Andal,<sup>2</sup> and M. Shanmugasundaram<sup>3</sup>

<sup>1</sup>Department of Civil Engineering, Syed Ammal Engineering College, Ramanathapuram, Tamil Nadu 623502, India

<sup>2</sup>Department of Civil Engineering, Velammal College of Engineering and Technology, Madurai, Tamil Nadu 625009, India

<sup>3</sup>Department of Civil Engineering, Valliammai Engineering College, Kancheepuram, Tamil Nadu 603203, India

Correspondence should be addressed to K. Senthamarai Kannan; [ksklkannan@gmail.com](mailto:ksklkannan@gmail.com)

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In the detailed study presented in this paper, an attempt was made to study the strength of cement when cenosphere (CS) and silica fume (SF) were used as replacement. Tests were carried out on mix with cenosphere as replacement for cement which has 12% of constant replacement of silica fume to the mass of cement, and this is made to stabilize the strength which was lost due to addition of cenosphere. From the test results, it was concluded that the strength loss of binder due to replacement of cenosphere can be stabilized by silica fume and still a safe value of strength can be achieved. Furthermore, the strength reduction is due to the consumption of hydration products and cloggy microstructure as observed in this study.

## 1. Introduction

A cenosphere is a lightweight, hollow sphere made largely of silica and alumina and filled with air, metals, or gas. The cenosphere was produced as a byproduct of coal combustion at thermal power plants. Blanco et al. [1] used powder-packing principle to produce lightweight concrete with cenospheres as primary “aggregate.” With this cenosphere, an ultralight-weight concrete can be manufactured with  $1430 \text{ kg/m}^3$  with compressive strength of 60 MPa [2]. It was also found that the surface modification of cenospheres accompanied by compatibilization led to the substantial improvement of mechanical properties and thermal stability of the composites [3]. The mechanical properties of polymer-cenospheres composites are inferior owing to poor interfacial interactions between the hydrophilic cenospheres surface and the hydrophilic polymer [4]. Thus, tetrasulphane modified cenosphere can be used as reinforcing filler [5]. It was found that cenospheres were not deleterious due to alkali silica reaction; also, fine cenospheres showed limited pozzolanic reactivity at  $28\text{--}30^\circ\text{C}$  and  $38^\circ\text{C}$  but exhibited significant pozzolanic reactivity at  $80^\circ\text{C}$  with aluminum tobermorite [ $\text{Ca}_5\text{Si}_5\text{Al}(\text{OH})\text{O}_{17}\cdot 5\text{H}_2\text{O}$ ] and this was

identified as the main reaction product [6]. The cenosphere-concrete composites show a structure of disintegrated pores, leading to low permeability; the pores were also found in the range of 2 to 5 micron meter [7]. The lightweight concrete prepared with powder-packing theory in order to obtain concrete with the lowest possible density was tested and the results show the loss of resistance to compression in dependence on density [1]. Cenospheres in fly ash-cement systems appear to act as energy-dissipating inclusions in fracture and do not necessarily weaken the system [8]. As for a matrix to maintain the strength of binding material, we had used silica fume. Silica particles with the size from 100 nm to  $2 \mu\text{m}$  were chosen [9]. In addition, silica is known to be used in construction industry to increase the strength of concrete as micro-filler and a reactant in pozzolanic reaction during cement hydration [10]. It was proved that silica fume with 5%, 10%, and 12% of replacement with an adequate amount of super plasticizer and W/B ratio improves the properties of cement grout [11]. It was also proved that addition of finer particles will ensure higher durability [12]. In the present study, the effect of cenosphere along with silica fume on the properties of binding material was investigated.

TABLE 1: Properties of cement, cenosphere, and silica fume.

(a)			
	Physical properties		
	Cement	Cenosphere	Silica fume
Blaine surface			
Area (m <sup>2</sup> /Kg)	380	320	1500
Particle mean			
Dia (μm)	<32	<100	<1
Specific gravity	3.1	0.9	2.3
Loss of ignition	2%	1.30%	—
(b)			
	Chemical properties		
	Cement	Cenosphere	Silica fume
SiO <sub>2</sub>	23%	65.00%	89.00%
Al <sub>2</sub> O <sub>3</sub>	4.20%	36.00%	10%
MgO	0.20%	2.50%	—
Fe <sub>2</sub> O <sub>3</sub>	1.20%	3.00%	2%
CaO	63%	0.50%	0.45%

## 2. Materials and Experimental Investigation

**2.1. Materials Used in This Study.** Ordinary Portland cement conforming to IS: 12269 (Indian Standard Designation, IS: 12269-1987) was used for this study. River sand obtained from Tamil Nadu Minerals Limited (State Government of Tamil Nadu) with specific gravity of 2.65 and fineness modulus of 2.64 was used as fine aggregate. In the present investigation, potable water was used. The cenospheres used in this study were obtained from Ash Tech, and Elkem silica fume was used. The properties of cement, cenosphere, and silica fume were given in Table 1.

**2.2. Experimental Methods for Investigation.** The mortar cubes were prepared with 1 : 3 of cement : fine aggregate ratio and water/binder ratio was fixed as 0.45; with this proportion, the mortars were prepared using mortar mixing machines. The cenosphere was used as replacement to cement up to 30% by weight of cement and the details of replacement were presented in Table 2. The mortar cubes of size 70.6 mm × 70.6 mm × 70.6 mm conforming to IS: 10080-1982 were tested for compressive strength at 7 days, 14 days, and 28 days of age. Each layer is well compacted by a tamping rod of 12 mm diameter. After the compaction, the top surface is levelled using a trowel and left for 24 hours to dry in room temperature of 31°C with 75% humidity. On the next day, at room temperature of 30°C and 60% humidity, the mortar cubes are kept inside a curing tank filled with potable water. The specimens are tested with a 2000 kN capacity hydraulic compression testing machine, as per IS: 4031-1982 (Part 6).

The specimens were also studied by scanning electron microscopy and XRD Patterns. Samples for scanning electron microscopy (SEM) analysis are taken near the surface (0-1 mm depth) of specimens. Microstructural studies utilized

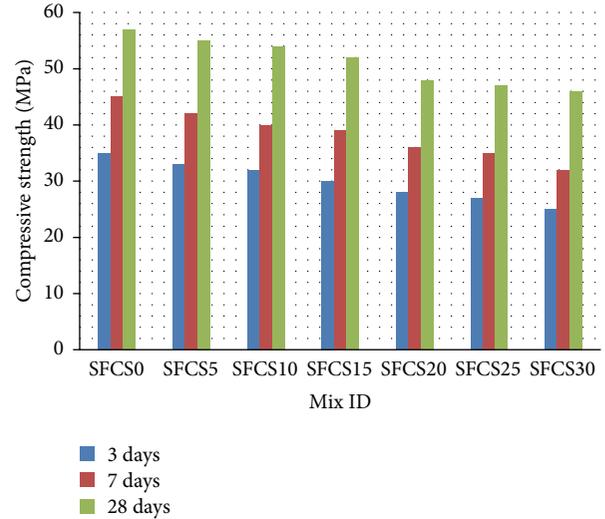


FIGURE 1: Compressive strength of mortar cubes.

SEM (Hitachi S-3000H, Japan) equipped with EDAX analyzer for microstructural observations of the surfaces, which is coated with evaporated copper for examination. A SEM analysis is done at a maximum magnification of 5000x with energy 20 keV and a high resolution of 3.5 nm. For this analysis, samples of size 10 mm cubes are cut with a saw cutter on 28th day. The XRD analysis is carried out with a Siemens D-5000 X-ray diffractometer with Cu K-beta radiation and 2 scanning with a step size of 0.02° and a measuring time of 10.00 Deg/minute. A voltage of 40 kV and current of 15 mA are used. Samples are collected from the cubes after 28 days of water curing and powdered in ball mills to pass through the sieve size of 90 μ.

## 3. Results and Discussions

**3.1. Compressive Strength of Mortar Cubes.** At 3 days, 7 days, and 28 days, the mortar cubes strength were tested and the results were discussed in Table 2 and Figure 1. The results show that the addition of cenosphere alone reduces the mechanical strength of mortar; instead, the strength can be stabilized using silica fume as constant replacement in cement. The test results at 3 days strength show that the strength of SFCS5, SFCS10, SFCS15, SFCS20, SFCS25, and SFCS30 decreases by 5.71%, 8.57%, 14.29%, 20%, 22.86, and 28.57% in comparison with SFCS0. The test results at 7 days strength show that the strength of SFCS5, SFCS10, SFCS15, SFCS20, SFCS25, and SFCS30 decreases by 7.37%, 10.71%, 12.95%, 20.20%, 22.99, and 26.69% in comparison with SFCS0. The test results at 28 days strength show that the strength of SFCS5, SFCS10, SFCS15, SFCS20, SFCS25, and SFCS30 decreases by 4.36%, 5.57%, 10.10%, 15.85%, 18.29%, and 20.03% in comparison with SFCS0.

It was noted that all the values of SFCS series are more than the required target strength which is required for a 43 Grade cement which has a value of 43 MPa, and the same pattern was observed on all ages. Also, it was noted that as the ages increase the strength variation with SFCS0 decreases,

TABLE 2: Results on compressive strength of mortar cubes.

S. Number	Mix ID	% replacement of cenosphere to cement	Compressive strength in MPa		
			3 days	7 days	28 days
1	SFCS0	0	35	45	57
2	SFCS5	5	33	42	55
3	SFCS10	10	32	40	54
4	SFCS15	15	30	39	52
5	SFCS20	20	28	36	48
6	SFCS25	25	27	35	47
7	SFCS30	30	25	32	46

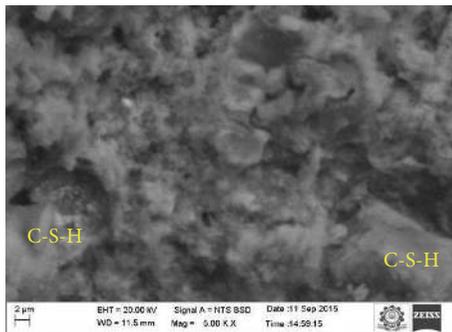


FIGURE 2: SEM image for SFCS0 specimen.

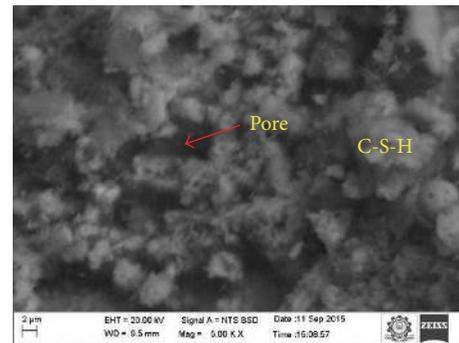


FIGURE 4: SEM image for SFCS10 specimen.

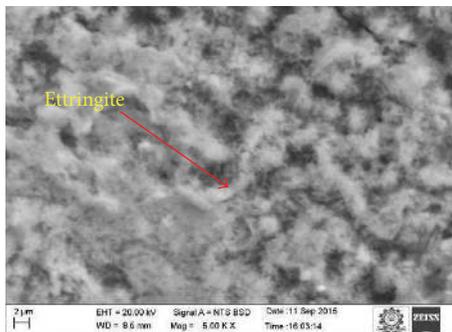


FIGURE 3: SEM image for SFCS5 specimen.

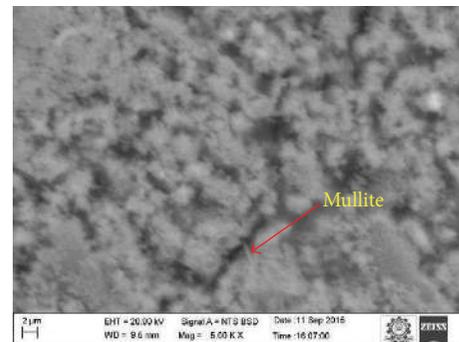


FIGURE 5: SEM image for SFCS15 specimen.

which shows that the active cenosphere content present in cement as replacement delays the strength attainment which may in turn reduces the microstructural cracks and their shrinkage. It has also been observed that the density gets reduced [1, 13].

**3.2. SEM and XRD Analysis.** Figure 2 shows the micrograph of SFCS0 specimen, and this shows the denseness of control specimen along with hydration products. The control specimen behaved as would have been predicted by literature. Considerable amount of calcium hydroxide formation was observed in the specimen. The SFCS5 micrograph was shown in Figure 3 which has clustered structure. The structure was due to the presence of alumina silicate in cenosphere and silica from silica fume. The formation of ettringite was also observed [14]; this may be due to the reduction in hydration

which can be substantiated by the earlier studies [15]. Figure 4 shows the SEM image of SFCS10 specimen, the disintegration is due to the consumption of calcium hydroxide due to the pozzolanic reaction and carbonation effect. But still the reaction of silica fume holds the structural integrity through its silicious effects [1]. Figure 5 shows the SEM image of SFCS15 specimen, and, from the observation, it is evident that the presence of mullite and aluminosilicate by the addition of cenosphere replaces the spaces created by the absence of portlandite [16, 17]. Also, some microstructural cracks were identified through the image. Figure 6, SEM image for SFCS20, shows that the cenosphere starts to appear in abundance which is due to the higher percentage replacement of cenosphere. The traces of ettringite were also observed

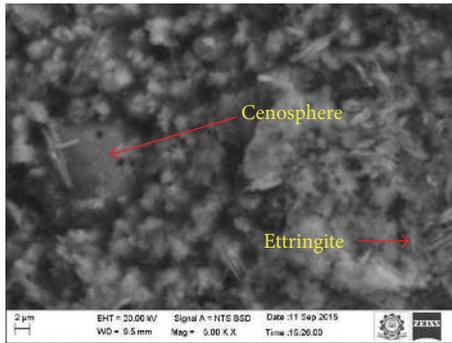


FIGURE 6: SEM image for SFCS20 specimen.

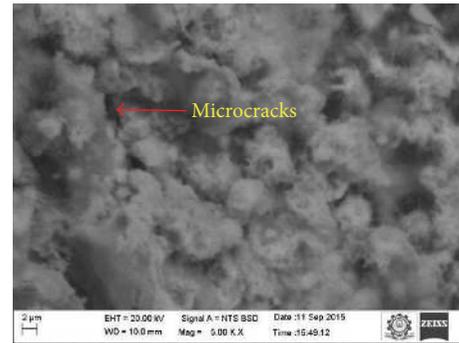


FIGURE 8: SEM image for SFCS30 specimen.

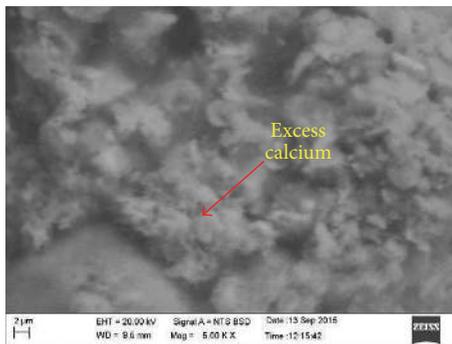


FIGURE 7: SEM image for SFCS25 specimen.

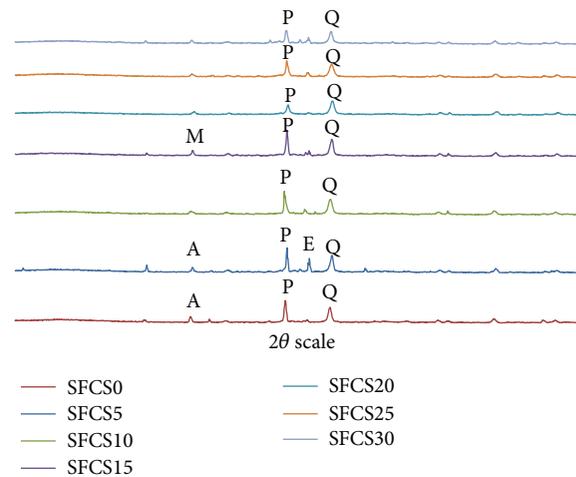


FIGURE 9: XRD analysis result in 2θ scale. P: portlandite; Q: quartz; A: aluminosilicate; E: ettringite; M: mullite.

and it is substantiated by the XRD graph in Figure 9. The micrograph shows that the silica fume and cenosphere were well dispersed inside the structure and the bonding was maintained. Figure 7 shows the micrograph for the specimen SFCS25; the structure is disintegrated and it is due to the reaction of excess calcium from cenosphere over the pozzolanic products. The surface becomes cloggy and the abundance of cenosphere was also noted. The SEM image of SFCS30 is shown in Figure 8 and the microstructure is completely disintegrated and shows heavier cracks. Even the occurrence of hydration products was very low and was confirmed through the XRD graph in Figure 9. From all the observations of SEM images from Figures 2–8, it can be identified that the cenosphere has an effect on microstructural part of the cement mortars. The censerophers behave initially as fillers, and, as the percentage of replacement increases, it reacts with the hydration materials causing the structure to become disintegrated and creation of microstructural cracks which in terms affects the strength and performance of the mortars. The cement pastes with higher replacement of censerophers have tortuous and cracked patterns. The interaction shows the boundary layer separation between cenosphere and the cement paste and the crack passes through these regions. This separation is due to the less adhesion between the cenosphere and calcium hydroxides present in the paste. Most of the cracks go through the censerophers which shows the energy-dissipating mechanism. Also, the cenosphere surfaces parted from cement materials showed less chemical reaction [6, 8].

Figure 8 shows the results of XRD analysis. The excess alumina silicate in cenosphere attributed to the reduction in strength of the mortar. These alumina and silicate have effect on the pozzolanic reaction, hence forming void in the region of pozzolanic products. The abundance of mullite is also related to the percentage of replacement of cenosphere. The occurrence of portlandite reduces with increase in percentage of cenosphere and the trace of ettringite is observed in specimens with higher percentage of cenosphere. The XRD results show that the addition of censerophers improves the crystallization of hydration products. The chemical reaction between the cenosphere and hydration product was observed and this attributed to the decrease of portlandite and its formation [18]. And this results in the disintegrated microstructure. Thus, excessive addition of cenosphere may result in the inferior quality of cement mortars and reduced mechanical performance.

Thus, from the above studies, the cement mortar with replacement of cenosphere along with silica fume performs well with a reasonable amount of cenosphere; as the percentage of cenosphere increases, the strength starts to decrease; hence, it should be noted that the strength loss due to the addition of cenosphere should be well balanced by means of strength enhancing technique.

## 4. Conclusions

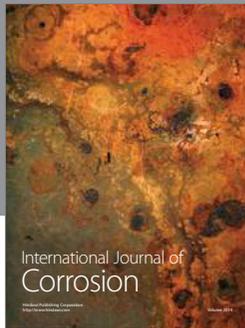
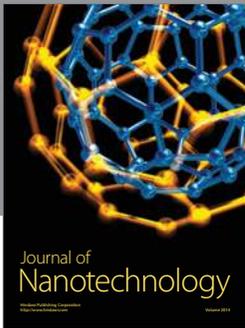
This study demonstrated that mortar cubes can be produced with combination of cenosphere and silica fume as a replacement for cement. The test on mortar cubes revealed that cement losses its strength due to replacement of cenosphere, but the strength loss can be stabilized by adding silica fume. The specimens even though loss their strength and the strength limit falls within the safer limit and confirms required strength. The strength decrement reduces by ages, showing that the strength attainment is slowed by the addition of cenosphere. The microstructure was also studied and it shows the disintegrated structures on higher replacement of cenosphere. It was also noted that the hydration products react with cenospheres, and, due to this, reduction in quantity of portlandite was observed resulting in strength decrement.

## Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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